Conservation Design: Managing Stormwater through Maximizing Preventive Nonstructural Practices

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Abstract

Unlike conventional methods of stormwater management that prioritize peak rate control to mitigate post-development downstream flooding effects, Conservation Design first aims to prevent or minimize the creation of stormwater from the outset. *Preventive* Conservation Design methods are defined in this paper as those that integrate stormwater management into the initial stages of project design, instead of waiting to consider them in the final steps of the site planning process. Mitigative Conservation Design techniques will be explored that use natural processes performed by vegetation and soil to mitigate unavoidable stormwater runoff impacts once prevention has been maximized to the greatest extent possible. Underlying these techniques-whether preventive or mitigative in nature-is a comprehensive perspective of water resources that views stormwater as an asset to be managed, not a waste for disposal.

This paper summarizes a recent project which the Brandywine Conservancy undertook for the Delaware Department of Natural Resources and Environmental Control, with support from USEPA Section 319 funding. For interested readers, *Conservation Design for Stormwater Management: A Design Approach to Reduce Stormwater Impacts from land Development* (Delaware Department of Natural Resources and Environmental Control with Brandywine Conservancy, 1997) further details all aspects of the Conservation Design program described here. This manual is referenced throughout this paper and is available by contacting DNREC at 302-739-4411 in Dover DE.

Introduction

Most Stormwater management programs place a heavy reliance on implementation of structural stormwater managementfacilities: detention basins, conveyance piping and inlet/outlet structures. These facilities-though created to mitigate negative stormwater impacts by controlling flooding-cannot in and of themselves eliminate adverse impacts of urban development throughout a watershed. In fact, because these systems fail to acknowledge and plan for critical system-wide water cycle processes, stormwater management itself can become a problem, rather than a solution. This is especially true when conventional stormwater management systems are combined with conventional large-lot subdivision designs.

The negative effects of this type of development and conventional stormwater management have been described in a variety of recent studies and reports, including the *Pennsylvania Handbook of Best Management Practices for Developing Areas* (CH2MHill, 1998) and a variety of other state stormwater manuals; Center for Watershed Protection publications such as *Better Site Design: A Handbook for Changing Development Rules in Your Community* (Center for Watershed Protection, 1998) and *Planning for Urban Stream Protection* (Schueler, 1995); the Northeastern Illinois Planning Commission's *Reducing the Impacts of Urban Runoff: The Advantages of Alternative Site Design Approaches* (Northeastern Illinois Planning Commission, 1997), and *Urban Stormwater Best Management Practices for Northeastern Illinois* (Northeastern Illinois Planning Commission, 1993). These effects include:

- Altered site hydrology and reduced groundwater recharge
- Reduced stream base flows
- Altered stream geomorphology (resulting in damaged aquatic habitat)

- Loss of site area for other uses (e.g.; recreation)
- Single purpose: disregards site resource conservation benefits
- Lack of attention to water quality
- High construction costs
- Maintenance burdens and costs
- Negative visual appearance (e.g., basins often fenced off)
- Limited number of stormwater discharge points
- Less flexibility in design

Conservation Design reflects a totally different philosophy toward land development that integrates stormwater management into the very core of site design, as opposed to considering it a problem to be resolved after the design has been completed. This philosophy regards stormwater as a key component of the hydrologic cycle and critical to maintaining the water balance-and groundwater reserves-for a particular watershed.

Recently we have come to realize that land development's impacts to water resources are not one-dimensional. They include, in addition to flooding, the multiple concerns of water quality, groundwater quantity, stream and wetland characteristics, in-stream habitat, and biodiversity. Therefore, stormwater management and site design must be approached much more comprehensively. At the foundation of this comprehensive approach lies an understanding of the relationship between land development and our water resources. In order to better comprehend this relationship, we must understand the water cycle itself-the amount of rainfall, evapo-transpiration, groundwater infiltration, and runoff-and how this cycle is affected by the characteristics of an individual site such as soil types, topography, and vegetation.

The Water Cycle and Landscape Dynamics

Appreciation of the water cycle is especially important to achieve successful, comprehensive stormwater management (Figure 1). In fact, only through understanding full water cycle dynamics, can we hope to achieve some sort of system balance and minimize negative stormwater impacts. Figure 2 displays a generic flow chart of the water cycle that highlights the various components of this cycle and how they are interconnected **(Conservation Design for Stormwater Management, 1997).** It is important to appreciate that the system itself is a closed loop: what goes in, must come out. If inputs to infiltration are decreased by 10 inches, then inputs to surface runoff and/or depression storage must be increased by this same amount. Furthermore, infiltration outputs must also be decreased: following along on the flow diagram, the groundwater reservoir, evapo-transpiration and soil moisture elements together will be reduced by this 10 inches, which will reduce stream baseflows.

The logical first step in any discussion of the water cycle is *precipitation-h* all its various forms. In southeast Pennsylvania, and indeed throughout much of the Mid-Atlantic states, the climate is relatively humid **(*Conservation* Design *for Stormwater* Management 1997, based on Hydrosphere 1992 database).** Substantial precipitation tends to be distributed throughout the year in frequent events of modest size. This consistency in rainfall throughout the year indicates that this region does not have a defined wet or dry season as do other areas of the country. This rainfall potential throughout the year has significant implications for consideration of stormwater runoff. For example, having rainfall throughout the year indicates that sediment laden runoff can occur at any time; therefore, it is important to establish some sort of erosion-controlling groundcover during all seasons of the year.

Also important is the distribution of rainfall by size of event. Based on analysis of 35 years of data from a Wilmington, Delaware rain gage ***(Conservation Design for Stormwater Management* 1997)**, it is clear that the precipitation occurs mostly in small "events" or storm intensities. Ninety-eight percent of the total *number* of events during this extended period were classified in the "less than 2 inches" category. Even more important from a water cycle perspective, 96% of the average annual rainfall *volume* occurred in storms of less than 3 inches (which is less than the 2-year, 24 hour

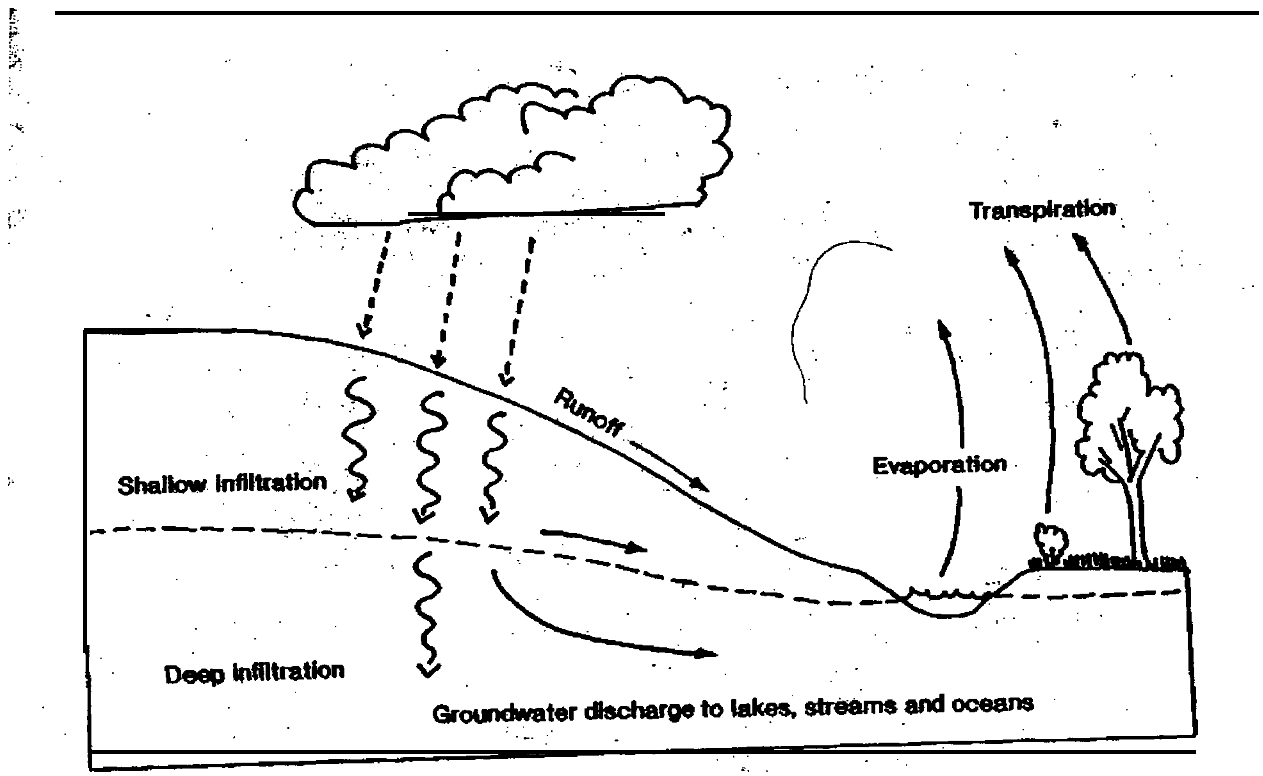

Figure 1. The Water Cycle.

storm). This understanding of storm size distribution is critical for a variety of reasons in stormwater management. For example, if our concern is keeping the water cycle in relative balance, capturing and recharging the 1 - or 2-year storm as the basis for design will encompass the vast bulk of precipitation and stormwater runoff volumes in the average year and provide adequate water cycle balance. This leads to very different design criteria than if flooding (peak runoff rates) is the only concern addressed.

Another key component of the water cycle is the linkage between stormwater infiltration, groundwater recharge and stream baseflow. As land is developed and impervious coverage increased, less water is recharged to groundwater aquifers **(Thomas Dunne and Luna Leopold's *Wafer in Environmental Planning* [Dunne and Luna, 1978] is an excellent background text in addition to the above referenced reports).** As these subtractions continue acre-by-acre, development-by-development, their cumulative effects grow larger. Also, as development occurs, more water is often withdrawn from the underground reserves for drinking, irrigation, or commercial uses, As subtractions are made from the groundwater reservoir flow, the impact will be seen in the form of a lowered water table and reduced stream baseflow discharge. Headwater springs and first-order streams-the lifeblood of our stream systems-may even dry up. The baseflow from headwater zones is critical to maintaining a diversity of aquatic plant and animal life, as well as terrestrial animals dependent on certain aquatic species for survival. In some cases the groundwater reservoir does not discharge to a stream, but rather to a wetland. In these instances, reduced infiltration and a lowered water table ultimately translate into a loss of wetlands themselves, and an elimination of their rich and vibrant ecological function.

A final component of the water cycle that must be addressed is overland runoff. This is the component most frequently addressed in conventional stormwater management approaches, for it is the cause of increased downstream flooding. Three major elements determine the volume and character of stormwater runoff for a given storm intensity: soil type, land cover (including vegetation and debris), and slopes. Soils vary widely in their ability to infiltrate stormwater and

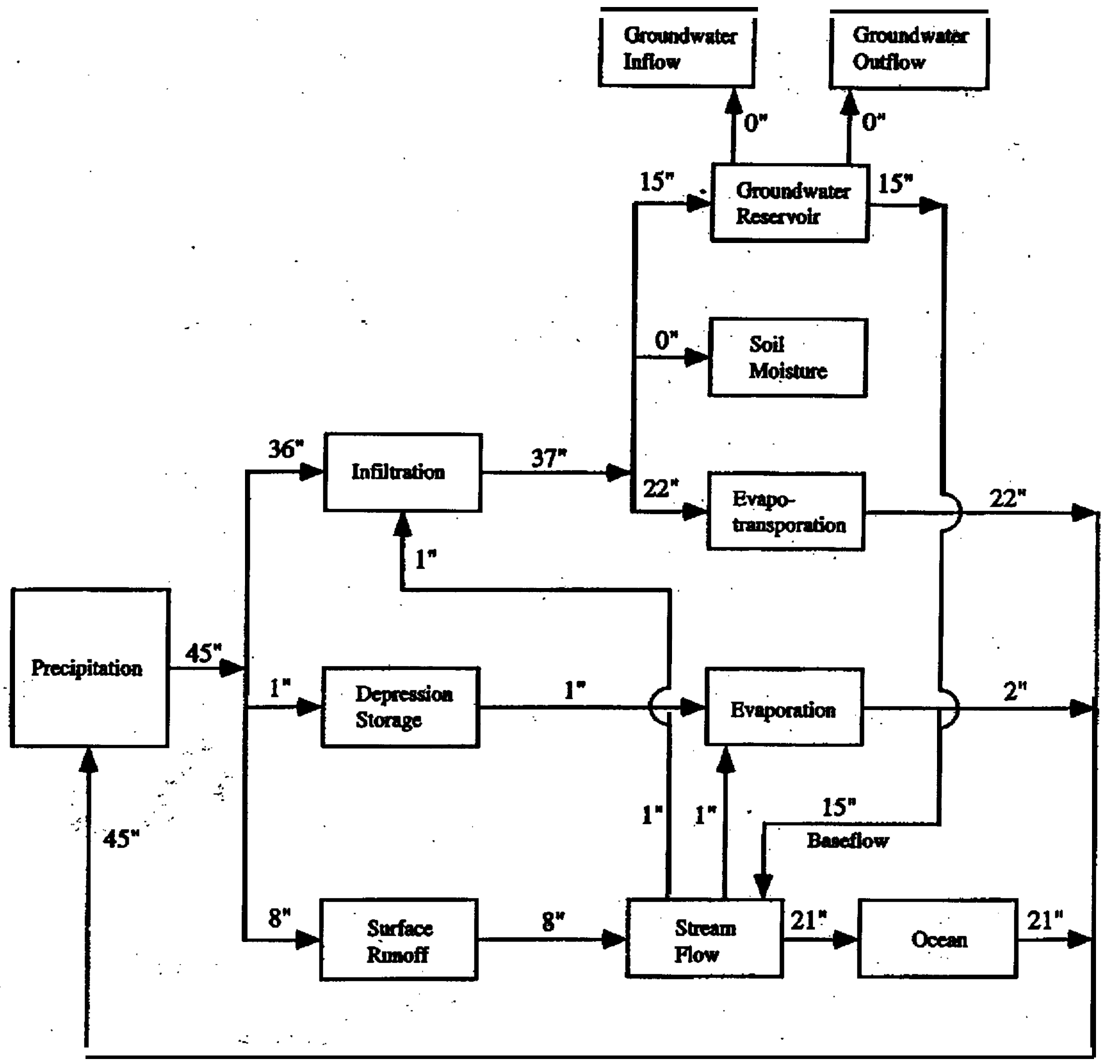

Figure 2. Water Cycle System Flow Chart.

minimize runoff and are classified accordingly by the USDA Natural Resources Conservation Service (NRCS) into four categories based on their permeability rates (Hydrologic Soil Groups A through D, with A having best permeability).

Land cover greatly affects the rate and volume of stormwater runoff and has significant water *quality* impacts as well. Obviously, the landcover of greatest concern for stormwater management is impervious coverage created through the development process. Interestingly, compacted lawns and cultivated fields can have significant runoff rates as well, especially when no crop covers the bare soil. The landcover in this region best suited to retard stormwater runoff and assist in its infiltration is the natural one: the piedmont forest. A mature forest can absorb much more water than an equivalent area of turf grass due to the presence of an organic litter layer and herbaceous and woody plant material. The organic litter layer on the forest floor provides a physical barrier to sediments, maintains surface soil porosity, and assists in denitrification and other water quality functions. The vegetation, both herbaceous and woody, physically retards runoff and erosion with its spreading root mats and also assists in maintaining soil permeability and water quality by taking up nutrients through its root systems.

Finally, slopes are another critical component of the stormwater runoff equation. Steeper slopescan accelerate runoff and increase the erosive force of the water. Therefore, removing vegetation on steeper slopes can have dramatic impacts on downslope aquatic systems.

As seen above, the water cycle and the implications for stormwater management are complex and comprehensive. The process of urbanization dramatically impacts the functioning of this water cycle. Conservation Design has been developed to address the issues of comprehensive stormwater management and to address the land use patterns that impact it.

Land Use and Site Development Impacts

Throughout much of the United States, farmland and natural areas are converted to suburban development at an ever accelerating pace. In fact there is hardly a city in America that does not occupy at least two to three times more land area than in 1970, even if population has not increased proportionately. This history of land use change is certainly true of the Mid-Atlantic states, where communities continue to grapple with the effects of unmitigated suburban sprawl.

The dynamic nature of wet-weather flow regimes and landscape ecology make it difficult to assess the impact of urbanization on aspects of the water cycle such as groundwater reserves and aquatic habitat. However, studies have indicated that the biological community in urban streams isfundamentallychanged to a lower ecological quality than what was there before development occurred. In one study in Delaware, approximately 70% of the macroinvertebrate community found in streams of undeveloped forested watersheds was comprised of pollution sensitive mayflies, stoneflies, and caddisflies, compared to 20% for urbanized watersheds (Maxted and Shaver 1996). Other studies suggest that the decay in stream quality is very rapid in the early stages of watershed urbanization; watersheds with less than 10% impervious cover are the most susceptible to the adverse effects of urbanization. Therefore early intervention as a watershed begins to develop is critical, and furthermore, this intervention should include measures to address stormwater management and land use in a connected, comprehensive manner.

In addition to in-stream habitat impacts, the issue of land development and water resources also has great implications for our human communities well beyond the issue of flooding. Reduced stream baseflows and groundwater resources means decreased availability of drinking water supplies. Also, reduced baseflows result in less available water for diluting the pollution output from industrial or municipal waste systems. As stormwater runoff increases, water quality can be greatly impacted by stream bank erosion, resuspension of sediment, runoff of chemicals and fertilizers from lawns and fields, and increased stream temperatures. Stormwater-linked pollutants vary with type of land use and intensity of use and have been shown to include bacteria, suspended solids, nutrients, hydrocarbons, metals, herbicides and pesticides, toxins and organic matter. Not only are these pollutants increased, but the landscape's natural capacity for filtering and chemical uptake through vegetation is decreased as land is cleared and paved. All of these pollutants can impact both drinking water supplies and natural aquatic systems.

Thus it becomes evident that if the negative effects of land development on our water resources are to be minimized, we must find alternatives to the conventional structural approach to stormwater management. Moreover, these alternatives must address the issue of land use and patterns of development in a comprehensive fashion, one that strives to maintain a hydrologic balance on site and replicate the pre-development hydrologic regime to the greatest extent possible. One approach-or collection of approaches-that can accomplish these goals is *Conservation Design.*

Conservation Design Principles

Stormwater management throughout the Commonwealth (and elsewhere) can be markedly improved by approaching stormwater differently than has been the practice in the past, where "stormwater management" has been defined largely as stormwater disposal. This different perspective challenges us to maximize prevention, even before stormwater becomes a problem, and to avoid highly engineered structural solutions that are expensive to build and maintain. In their place, Conservation Design focuses on utilization of natural systems and processes to achieve stormwater management objectives where feasible. At the same time, this new approach is intended to work with site resources-woodlands, soils, wetlands, etc.-to enhance their stormwater functions. The end result is a site design which minimizes stormwater generation and then mitigates the remaining stormwater in a low-impact manner, with an emphasis on groundwater recharge. Conservation Design is not so much a singular approach or solution as it is a *collection* of approaches and practices that are flexible enough to effectively address any given site and development program. Common to all these approaches and practices are several basic principles.

Achieve multiple objectives. Stormwater management should be comprehensive in scope, with techniques designed to achieve multiple stormwater objectives. These objectives include both peak rate and total volume control (i.e., balance with the hydrologic cycle), as well as water quality control and temperature maintenance. These objectives should include maintaining or improving the pre-development hydrologic regime.

Integrate stormwater management early into the site design process. Stormwater management tacked on at the end of the site design process almost invariably is flawed. To optimize comprehensive stormwater management objectives, stormwater management must be integrated into the first stages of the site planning. Stormwater impacts may even be a factor in determining type of use, extent of use, and location of the development on a site.

Prevent first, mitigate second. Approaches to site design which can reduce stormwater generation from the outset are the most effective approach to stormwater management. For example, effective clustering of units significantly reduces length of roads when compared to conventional development. Reduction in street width and driveway length can minimize impervious coverage. These type of approaches are rarely thought of as stormwater management practices, yet they achieve powerful stormwater quality and quantity benefits.

Manage stormwater as close to the source of generation as possible. From both an environmental and economic perspective, redirecting runoff back into the ground as close to the point of origin as possible, is preferable to constructing elaborate conveyance systems that increase flows and suffer from failures over time. Avoid concentrating stormwater. Disconnect, rather than connect, where feasible.

Engage natural processes in soil mantle and plant communities. The soil mantle offers critical groundwater recharge conveyance and pollutant removal functions through physical filtration, biological action, and chemical processing. Understanding how much of what type of soil is in place on any given site is essential when assessing stormwater management/water quality impacts and opportunities. Vegetation similarly provides substantial pollutant uptake/removal potential and can assist in infiltration by maintaining soil porosity and retarding runoff. In addition, naturally vegetated areas improve their stormwater functions over time as leaf litter and debris builds a richer organic soil layer. Areas of good soil permeabilities (A and B soils) and intact vegetative communities should be prioritized in prevention strategies.

A Conservation Design Procedure

The Conservation Design principles outlined above, though greatly simplified, can offer valuable guidance when approaching a particular land development project. In fact, these five principles form the basis for a Conservation Design Procedure. This Design Procedure incorporates both Preventive Approaches and Mitigative Practices. Preventive Approaches tend to be broader in geographic scope than other techniques and typically may influence some of the major decisions regarding a particular development project. Approaches may even transcend the site itself, involving an entire planning jurisdiction or area, or even an entire region. Also, Preventive Approaches attempt to reduce impervious coverage or minimally disturb the existing vegetation and soils in prime recharge areas. For example, a reduction in road width from 30 feet to 18 feet means an immediate 33.3% reduction in roadway imperviousness, which typically comprises a large portion of site imperviousness.

Mitigative Practices include mitigative techniques which are often more structural in nature. These practices encompass a rapidly growing array of biofiltration and bioretention methods that maximize the stormwater management potential of soils and vegetation. Mitigative Practices include vegetated swales for stormwater conveyance, vegetated filter strips and riparian buffers, grading, berming, terrraforming, and level spreading stormwater in natural areas. These practices should mitigate as close to the source as possible and achieve multiple objectives. For example, a berm, which is used to retain stormwater runoff on a forested slope, can double as a walking trail, thus decreasing the expense of two separate individual systems.

Figure 3 graphically displays the Design Procedure as a flow diagram. The procedure itself can be thought of as a series of questions which must be asked as Conservation Design is applied to each site. If site designers rigorously address all of these questions, the “answers”-the Conservation DesignPreventive Approaches and Mitigative

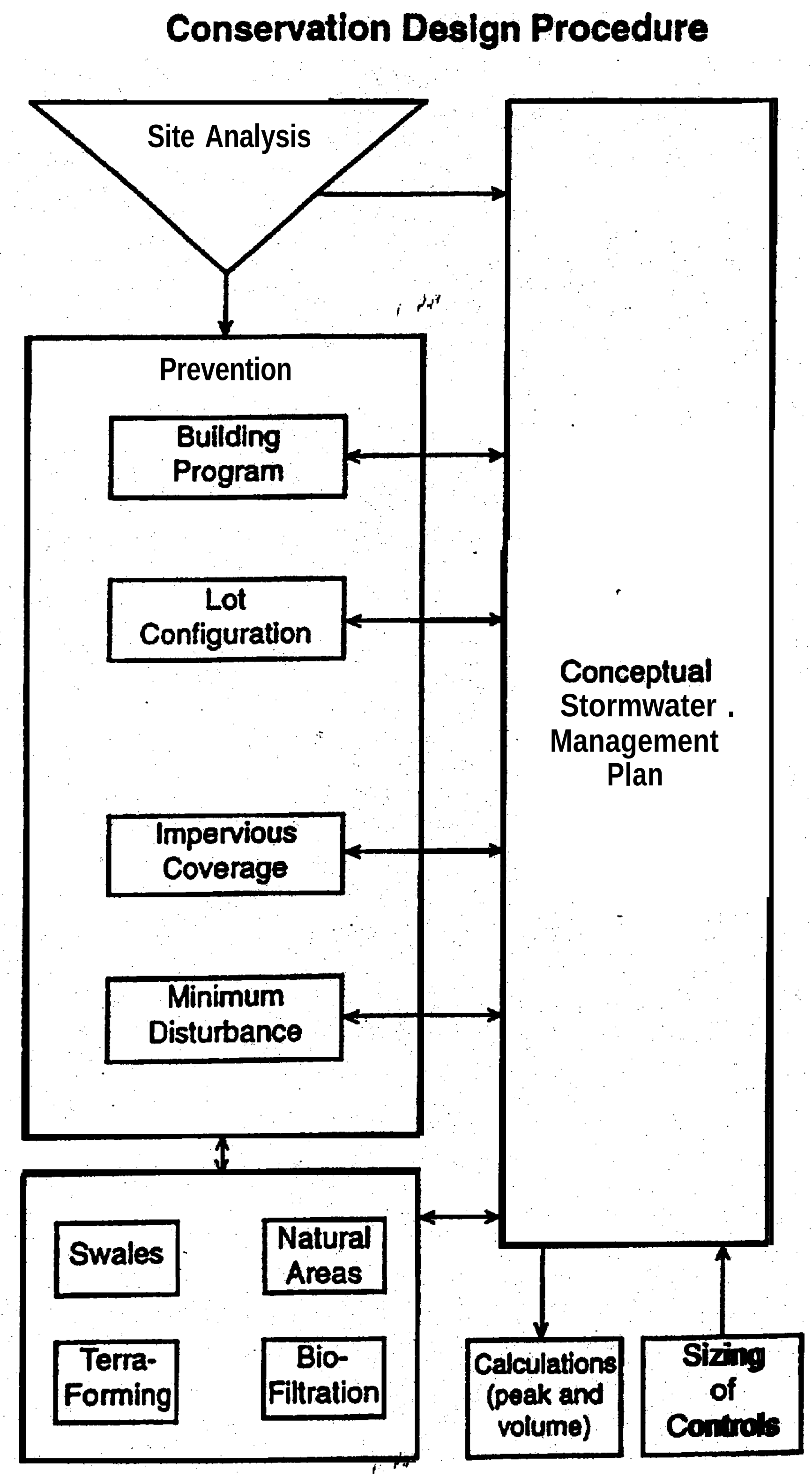

Figure 3. A Conservation Design Procedure.

Practices-will successfully be identified for each site. The overriding objective ultimately is to achieve a new way of thinking about site design. The procedure begins with an effective and complete Site Analysis, which can help identify both areas of concern and resourcesforopportunity in regard to stormwater management. The procedure then flows from macro, larger-scale preventive questions (i.e., how can the design be clustered to reduce site disturbance) to micro, small-scale mitigative questions (i.e., can stormwater be infiltrated in bioretention areas?). Probably the most important aspect of the procedure in Figure 3 is its positioning of the Conceptual Stormwater Management Plan as a concurrent task with the entire site design process. This reinforces the notion that stormwater management should be an integral part of the entire design process, including the site analysis.

In order to better understand the Conservation Design Procedure, each of its components (the Preventive Approaches and Mitigative Practices) is discussed in more detail below.

Site Analysis

Three major aspects need to be addressed in the Site Analysis process:

Site Background and Context

What is the surrounding context?

What is its location in the watershed?

In which geologic/geographic region is it located?

What is the site size?

What are adjacent uses and landcover?

Critical Natural Features

Existing hydrology?

Wetlands? Floodplains? Riparian buffers?

Steep slopes? Special habitat areas?

Stormwater Opportunity Areas

Where are soils that are best suited for stormwater recharge? Worst?

Where is existing landcover optimal to prevent stormwater?

What opportunities exist to use vegetation and soils in mitigation?

On what soils and slopes is this vegetation?

What is depth to bedrock or water table?

Preventive Approaches

The Preventive Approaches include a range of hierarchical questioning:

Building Program

What is the current zoning and density for this tract?

Is there currently an open space design option for the site?

Can the proposed building program be reduced in terms of density?

Can the type of unit or lot size be modified to promote open space?

What are the possibilities for water and sewer supply?

Lot Configuration

Have lots been reduced and open space been maximized?

Have lots been clustered to avoid critical areas of recharge?

Have lots been configured to take advantage of mitigative practices?

Impervious Coverage

Has development been clustered to reduce impervious surfaces?

Have road widths been minimized?

Have building setbacks been minimized to reduce driveway lengths?

Have parking ratios and needs been carefully examined?

Have needs and sizes of walkways been examined?

Minimum Disturbance

Has maximum total site area, including soils and vegetation, been protected from clearing and disturbance?

Are zones of undisturbed open space maximized?

Have buildings been sited carefully to reduce vegetation removal?

Can no-disturbance buffers be installed to limit zones of soil compaction?

Mitigative Practices

The Mitigative Practices include a tool box of options that promote groundwater recharge and improve water quality. These practices have been assigned to several groupings, although in many cases the practicesoverlap. Virtually all of these techniques make maximum use of vegetation and soil functions, so although they are all technically structures, they are of lower complexity and more rooted in natural process than conventional approaches.

Vegetated Swales

Vegetated swales are effective means of stormwater conveyance. At low slopes, they can recharge modest amounts of stormwater, filter it through vegetative processes, and slow it down.

Terraforming

Terraforming comes in a variety of techniques. These include constructing subtle berms along contour below undisturbed areas. The berms act as modest “dams” retaining the water for up-slope recharge. Also, subtle grading of depression areas promote retention and recharge throughout a site.

Level Spreading/Natural Areas

With a level spreader, stormwater spills over the lip of a long trench or berm, creating sheet flow across a broad area. The level spreaders slow down the intensity of runoff and discharge it over a large, adjoining vegetated area with good soils, which in turn filter it and assist in groundwater recharge. Filter strips are planted vegetated strips through which runoff passes that filter it and slow it down. Riparian buffers are vegetated zones along stream corridors that filter the stormwater passing through it and help minimize erosion. These techniques are most valuable when used in conjunction with preventive strategies that leave larger natural areas undisturbed in order to handle these additional stormwater inputs.

Bioretention/biofiltration

Bioretention is a popular name given to just about any type of device that utilizes vegetation and soil to manage stormwater flows. They can be subtle depressions that exist naturally and receive stormwater or depending on soil conditions, they may be physically constructed “pits” that are filled with permeable soils and planted with native vegetation that adapt to both wet and dry conditions. These systems can either be “on-line” (part of the stormwater conveyance flow) or “off-line” (separate from the rest of the stormwater management/mitigation system). In either case, they have modest ponding storage that is recharged over the course of time.

Other mitigative devices

Not all of the required volume storage to meet peak rate requirements for a given site may be attained through the practices outlined above. At times, it may be necessary to put in “structural” systems such as in-ground infiltration trenches, infiltration pipes, or stormwater wetlands. However, these systems should be explored only after both Preventive Approaches and Mitigative Practices of Conservation Design have been maximized to the greatest extent possible.

Conclusion

The Conservation Design Procedure is perhaps best characterized as a “check list” or protocol of questioning during the site design process. The key to this approach is its range of innovative, yet effective options, not afforded in conventional systems which tend to be standardized irrespective of the particular site. With Conservation Design, the approaches and practices can be combined in a variety of ways to minimize the impacts of development on the water cycle and still meet regulatory stormwater management criteria such as peak rate control. Often, because these approaches and practices tend to favor multiple objectives and nonstructural techniques, Conservation Design can be less expensive to install and maintain than conventional systems. Also, because they are largely based on soil and vegetative processes, conservation design techniques tend to improve in function overtime, while conventional detention basin systems tend to diminish in function over time. In terms of water quality, Conservation Design Approaches and Practices can outperform conventional systems. For example, filter strips and biofiltration areas can remove over 90% of the suspended solids, 40% of the phosphorous, and 20% of the nitrates (Dillaha et al. 1986 and 1989; Yu et al. 1993). In addition, reduced yard areas and increased forested zones prevent chemical runoff from lawns-a great contributor to non-point source pollution-at the outset.

Conservation Design is limited only by the creativity of the designer and the flexibility of the developer and regulatory agencies. It must be emphasized that the Conservation Design approach will not eliminate a need for structural systems in all cases; however, more often than not, Conservation Design can replace or reduce the need for structural practices while providing attractive site amenities. And in the process, the water cycle will be balanced, and forests and other sensitive resources will be preserved. In short, Conservation Design can do more with less, and more for less, than conventional approaches to stormwater management.

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